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Near Field Coupled Wireless Microwave Sensor

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***Abstract*—This paper presents a wireless planar microwave sensor operating at industrial scientific and medical (ISM) frequency for the detection of dielectric materials. The microwave sensor consists of a reader (ground defected microstrip coupled line) and a passive tag where a complementary split-ring resonator (CSRR) is made on the commercially available copper-foil. The CSRR is a peel-off type tag that is excited using the near field of microstrip coupled transmission line. The near field coupling, the low-cost passive tag design, and the high sensitivity (~250 MHz change per unit change in dielectric constant) make the proposed sensor wireless, cost-effective, and reliable.**

***Keywords*— Dielectric measurement, planar microwave sensor, near field coupling, wireless sensor.**

I. Introduction

Microwave planar sensors are prevalent among the high-frequency sensing industries and researchers. They have been demonstrated to provide accurate information about the small changes in the dielectric and magnetic properties of the material under test [1]-[13]. The dielectric and magnetic properties at microwave frequency do carry the intrinsic signature of materials on the macro scale. Since these properties are unique, the change in the material constitution due to adulteration, aging, chemical reaction, and contamination can quickly get noticed. Recently, the researchers have shown keen interest in characterizing the dielectric, magnetic and magnetodielectric materials using the planar sensors comprised of split-ring resonator (SRR) [2], [3], [7], [9], [11], complementary SRR (CSRR) [13]-[15], and the combination of SRR and CSRR [3], [7], [9], respectively. The chemical properties of liquids are of prime interest for biologist [15], and chemist that are being tested using flexible electronic skin [16]–[18], while the detection of the air bubble in glucose [1] and uric acid in sweat [19] is also being investigated for the application in the medical industry. Apart from the detection and characterization of the electrical and chemical properties, the sensing of other physical properties is quite attractive and currently being tested using microwave sensors. Recently, a rotation sensor [20-[21], direction sensor [22], angular velocity sensor [23], and proximity sensors [24] have been realized using planar photolithography techniques and working at microwave frequency. The proximity sensor works on the idea of near field coupling and can detect the displacement in the close proximity.

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In recent years, a few research groups have developed wireless microwave sensors for the detection of biological samples, chemical samples, pipeline integrity monitoring, organic vapor sensing, etc. [6], [25]–[28]. Wireless sensors usually need dedicated transmitting and receiving antennas as explained and utilized in [6], [25]–[27], while the positive feedback is required for increasing the quality factor, selectivity, and range of operation [28]-[29]. In high-frequency circuits, the device needs to be compact, and for this reason, planar technology is attractive, and it allows for having the transmitter and receiver circuitry on the same board, as shown in [30].

In this paper, we show that wireless sensing is possible using a simple arrangement of ground defected coupled transmission lines as the transmitter and receiver. At the same time, the CSRR is utilized as the passive Radio-frequency identification (RFID) tag. The novelty of the proposed sensor is a low-cost, compact design that provides the detection of plastics materials with high resolution, while the peel-off type tag engraved on a copper-foil adds flexibility in sample testing.

II. Design of Wireless Sensor

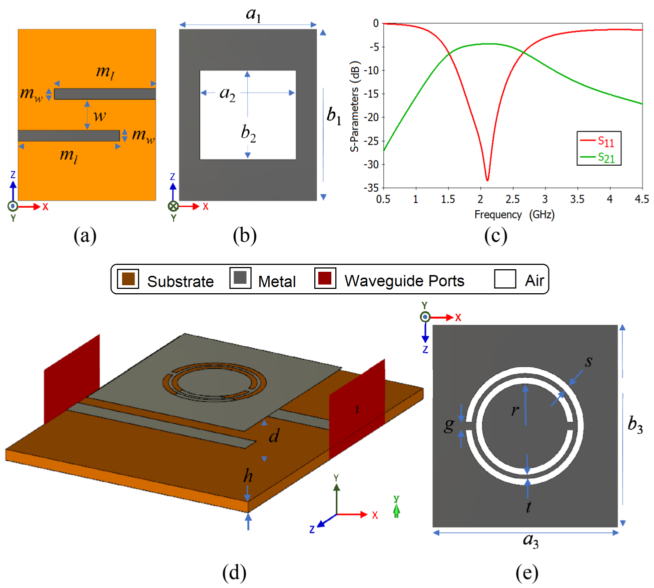


Fig. 1. Top and (b) bottom view of ground defected microstrip coupled line as monopole antennas, (c) transmission and reflection parameters of the structure shown in (a) and (b), (d) arrangement of tag above the transmitter and receiver section, (e) a detailed view of CSRR metal tag

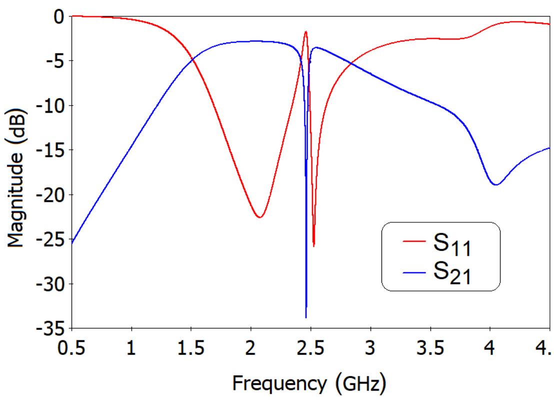
The sensor is designed on a 1.5 mm thick Taconic RF-35 dielectric substrate (dielectric constant 3.5, and loss tangent 0.0025) with 18 μm of metal thickness. The ground defected microstrip line usually performs like a monopole antenna; when excited, it can wirelessly transmit a signal through another identical antenna placed in close vicinity using near field coupling approach. The ground defect enhances the near field coupling by means of extending the current flow inside the edges of the cut in the ground plane. The design of near field coupled microstrip line with the defected ground is shown in Fig. 1(a) and (b), whereas the two-port scattering parameters are displayed in Fig 1(c). From Fig. 1(c), it can be seen that the transmission bandwidth is 1.45 GHz, and coupling attains maximum near the resonance of the defected patch in the ground plane. Table I summarizes the values of the design parameters.

The proposed sensor consists of the ground defected microstrip coupled line and a passive metal tag. The tag is a peel-off type CSRR–fabricated from a metal foil of thickness τ and can be applied easily on the surface of the material under test. The sensing arrangement of a reader and tag is shown in Fig. 1(d), while a detailed view of CSRR with various dimensions is provided in Fig. 1(e).

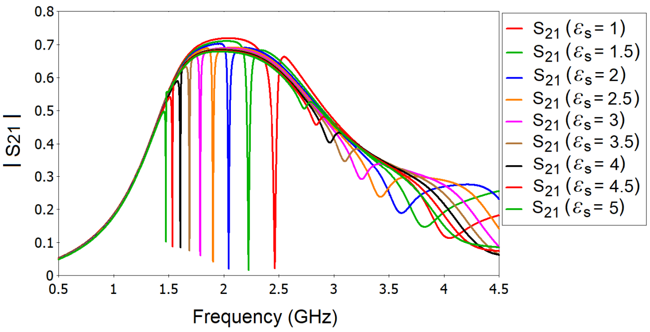
TABLE I. PARAMETERS OF PROPOSED SENSOR AND THEIR VALUES (MM)

Parameters	Value	Parameters	Value	Parameters	Value
a_1	40	a_2	28	a_3	25
b_1	50	b_2	26	b_3	25
d	5	m_l	29.5	m_w	3.2
g	1	h	1.5	r	5.3
s	1	t	0.5	w	9

III. NUMERICAL ANALYSIS AND RESULTS



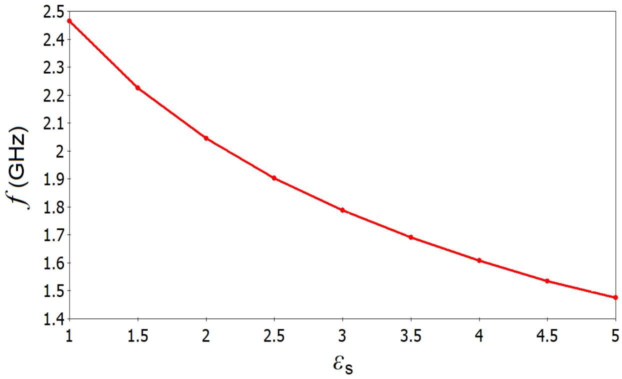
(a)



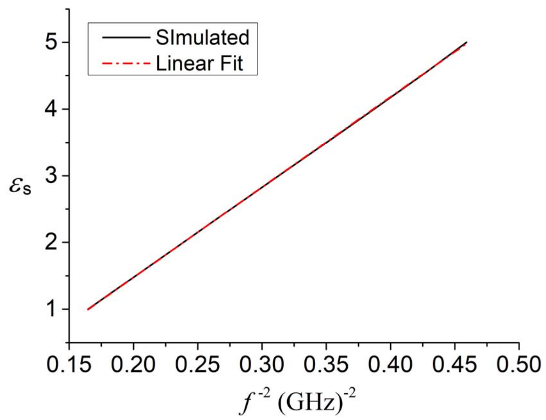
(b)

Fig. 2. (a) Scattering coefficients of the sensor with a metal tag on the top and (b) transmission characteristics of the sensor with the metal tag placed on various dielectric samples

The passive tag, when placed symmetrically above the reader, as shown in Fig. 1(d), selectively removes the resonant frequency of the tag from the transmission band shown in Fig. 1(c). The sensor arrangement, as shown in Fig. 1(d), is numerically tested, and it is found that the tag inscribed on a commercially available τ = 0.127 mm thick copper foil provides a sharp notch in the transmission characteristic at the resonant frequency, f = 2.47 GHz. The scattering coefficients of the sensor with the unloaded tag are shown in Fig. 2(a). For the measurement of unknown dielectric substrates, the tag is placed on the smooth surface of the sample, and the reader is positioned as shown in the arrangement of Fig 1(d). The transmission characteristics of the sensor for various dielectric slabs are recorded and given in Fig. 2(b).



(a)



(b)

Fig. 3. (a) Variation of resonant frequency and (b) mapping of the inverse square of the resonant frequency for various dielectric samples

From Fig. 3(a), two main points can be easily noticed, i.e., a) the sensor is quite sensitive for small changes in the dielectric constant of the sample under test, and b) the frequency response is not linear for the range of dielectric measurement. It is found that a unit change in dielectric constant provides, on average, a 250 MHz shift in the resonant frequency, which is quite attractive. The non-linear response can be attributed to the fact that the resonant frequency varies according to the inverse square root of the capacitance. This capacitance has a direct relationship with the dielectric constant of the sample under test. To get a meaningful relation between the unknown values of the dielectric constant of the sample under test and the calculated resonant frequency, the relative permittivity is plotted in Fig. 3(b) against the inverse square of the resonant frequency, f^{-2}. It is evident that now the relationship becomes linear. The simulation data in Fig. 3(b) are used to develop an empirical relation by curve fitting method. Thus gives the following formula:

$$\varepsilon_s = 13.542\left[f(\text{GHz})\right]^{-2} - 1.235 \quad (1)$$

The empirical relation (1) is valid for a maximum change in the resonant frequency up to 1 GHz. The initial results of numerical studies have shown that wireless measurement remains very sensitive for distance, d ranging from $d = 5$ mm to 10 mm; however, the sensitivity deteriorates with a further increase in the value of d.

IV. Conclusion

A wireless sensor operating in industrial scientific and medical (ISM) frequency of 2.47 GHz has been designed and numerically tested. The sensor is found to be quite sensitive for measuring the dielectrics having a low value of dielectric constant, which is quite useful in characterizing plastics and radomes and may find applications in the paper industry. Since one of the advantages of the proposed sensor is the peel-off type metal tag, the future work is to evaluate the sensor performance on the curved surface.

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